

*QUANTUM OPTICS WITH LASER COOLED  
AND TRAPPED ATOMS*

*FINAL PROGRESS REPORT*

*H. J. KIMBLE, PRINCIPAL INVESTIGATOR*

*MARCH 15, 1993 - MARCH 14, 1996*

*U. S. ARMY RESEARCH OFFICE*

*GRANT NUMBER: DAAH04-93-G-0074*

*CALIFORNIA INSTITUTE OF TECHNOLOGY  
1201 E. California Blvd.  
Norman Bridge Laboratory of Physics 12-33  
Pasadena, California 91125*

*APPROVED FOR PUBLIC RELEASE;*

*DISTRIBUTION UNLIMITED*

19970210 238

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comment regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE		3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE Quantum Optics with Laser Cooled and Trapped Atoms			5. FUNDING NUMBERS	
6. AUTHOR(S) H. J. Kimble, Principal Investigator			DAAH04-93-G-0074	
7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES) California Institute of Technology 1201 E. California Blvd. Norman Bridge Laboratory of Physics 12-33 Pasadena, California 91125			8. PERFORMING ORGANIZATION REPORT NUMBER Final Progress Report	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSORING / MONITORING AGENCY REPORT NUMBER ARO 30 932.3-PH	
11. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  An experimental investigation of a variety optical processes for laser cooled and trapped atoms has been carried out. The principal achievements of the research program have been (1) the first observation of cooling and trapping of a single neutral atom and (2) a detailed spectroscopic study of the $6D_{5/2}$ level in atomic Cesium made possible by two-photon excitation of a laser cooled and trapped sample. These advances are enabling accomplishments for diverse experiments in optical physics, including the realization of quantum logic with single atoms and photons and the exploration of atomic radiative processes with manifestly quantum or nonclassical excitation.				
14. SUBJECT TERMS			15. NUMBER OF PAGES 5	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OR REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

## Final Progress Report

### *Quantum Optics with Laser Cooled and Trapped Atoms*

*H. J. Kimble, Principal Investigator*

#### **A. Statement of Problem Studied**

The principal objective of this research program has been to exploit the unique properties of laser cooled and trapped atoms for diverse investigations in optical physics. At one extreme, it has been possible to isolate a single neutral atom within a volume of roughly  $(100\mu\text{m})^3$  for a mean interval of a second.<sup>[1]</sup> At the other extreme, the high density and low temperatures of an atomic vapor in a magneto-optical trap ("MOT") enables unique spectroscopic studies with high signal-to-noise ratio and small residual Doppler broadening.<sup>[2]</sup>

#### **B. Summary of Significant Results**

Perhaps the most important result obtained as part of the research program has been the isolation of a single atom in a MOT, as described in publication [1]. For this work, fluorescence from Cesium atoms in a MOT is detected under conditions of very low background density. Discrete steps are observed in the fluorescent signal and are associated with the arrival and departure of individual atoms in the trap. These observations are the first such measurements for individual atoms and provide an enabling capability for diverse investigations in optical physics with single atoms, including research in the areas of quantum logic and measurement, and in cavity quantum electrodynamics.

A second significant accomplishment has been the utilization of a trapped sample for high resolution spectroscopic studies of atomic structure. In particular, the work reported in publication [2] determines the hyperfine structure of the  $6D_{5/2}$  level in atomic Cesium at a level of 1%, which represents an approximate 30-fold improvement over a prior measurement made by level-crossing spectroscopy in a vapor cell. With this information about the structure of the  $6D_{5/2}$  level in hand, a variety of nonlinear spectroscopic possibilities have emerged, including the use of the  $6S_{1/2} \rightarrow 6P_{3/2} \rightarrow 6D_{5/2}$  transition for two-photon excitation with nonclassical ("squeezed") light and the exploitation of the trapped atomic sample for nonlinear mixing and demodulation of terahertz frequency offsets.

#### **C. List of Publications**

1. "Observation of a single atom in a magneto-optical trap," Z. Hu and H. J. Kimble, Optics Letters **19**, 1888 (1994).
2. "Two-photon spectroscopy of the  $6S_{1/2} \rightarrow 6D_{5/2}$  transition of trapped atomic cesium," N. Ph. Georgiades, E. S. Polzik, and H. J. Kimble, Optics Letters **19**, 1474 (1994).

#### **D. Participating Scientific Personnel**

Graduate students -

Zhen Hu, Ph.D. degree, California Institute of Technology, 1995

Nikos Ph. Georgiades (Ph.D. degree in progress)

Quentin Turchette, Ph.D. degree spring, 1997

Senior Personnel -

Dr. E. S. Polzik, who left Caltech to become Associate Professor of Physics, Aarhus University, Aarhus, Denmark

**MASTER COPY:** PLEASE KEEP THIS "MEMORANDUM OF TRANSMITTAL" BLANK FOR REPRODUCTION PURPOSES. WHEN REPORTS ARE GENERATED UNDER THE ARO SPONSORSHIP, FORWARD A COMPLETED COPY OF THIS FORM WITH EACH REPORT SHIPMENT TO THE ARO. THIS WILL ASSURE PROPER IDENTIFICATION. NOT TO BE USED FOR INTERIM PROGRESS REPORTS; SEE PAGE 1 FOR INTERIM PROGRESS REPORT INSTRUCTIONS.

**MEMORANDUM OF TRANSMITTAL**

U.S. Army Research Office  
ATTN: AMXRO-ICA-L (Hall)  
P.O. Box 12211  
Research Triangle Park, NC 27709-2211

<input type="checkbox"/> Reprint (Orig + 2 copies)	<input type="checkbox"/> Technical Report (Orig + 2 copies)
<input type="checkbox"/> Manuscript (1 copy)	<input checked="" type="checkbox"/> Final Progress Report (Orig + 2 copies)
<input type="checkbox"/> Related Material (1 copy)	

CONTRACT/GRANT NUMBER: DAAH04-G-0074

TITLE: Quantum Optics with Laser Cooled and Trapped Atoms

\_\_\_\_\_

is forwarded for your information.

SUBMITTED FOR PUBLICATION TO (applicable only if report is manuscript):

\_\_\_\_\_

\_\_\_\_\_

Sincerely,